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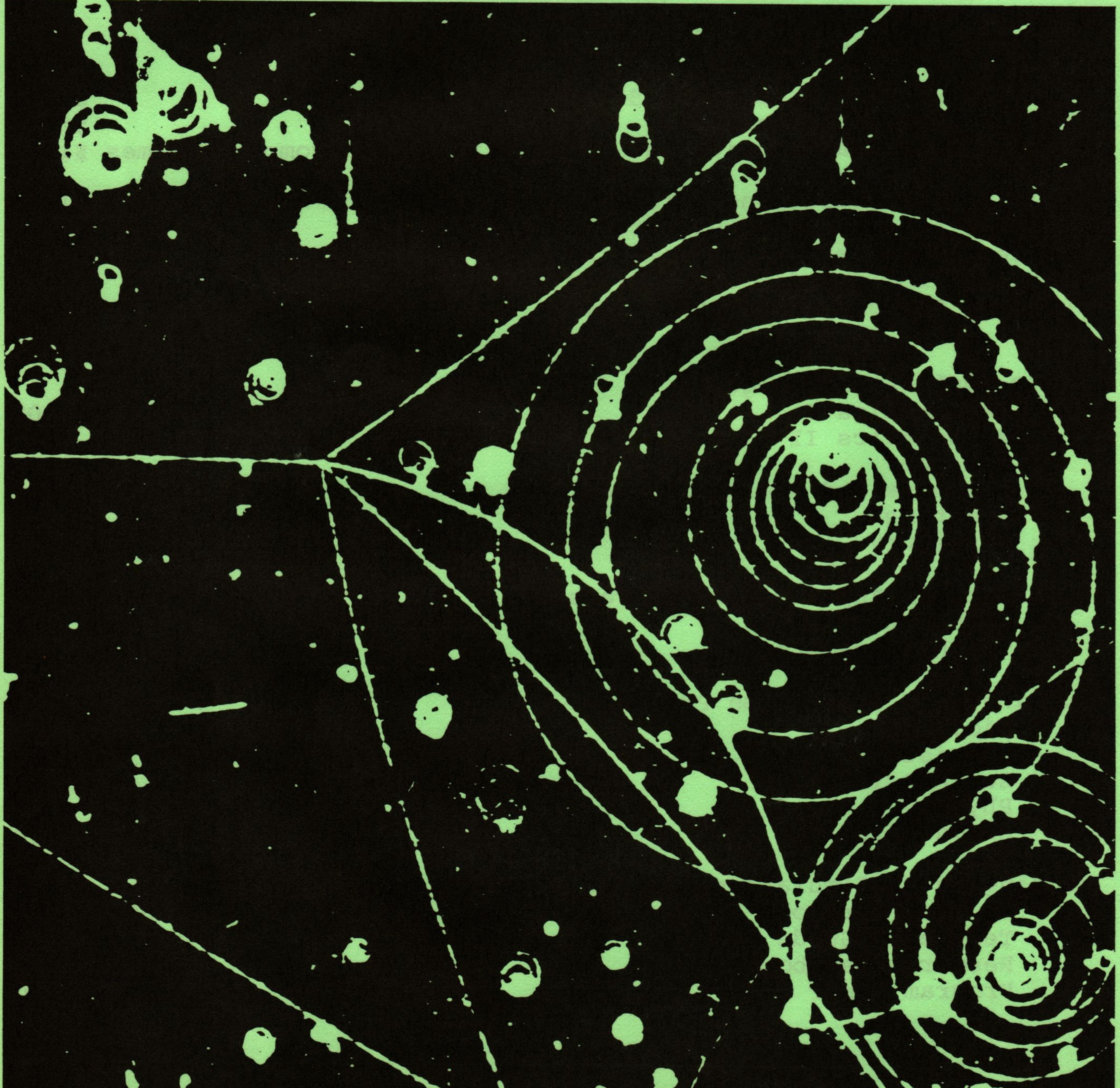

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SCATER

Resource Manual

A computer simulation of the use of alpha particle scattering to determine atomic structure

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HUNTINGTON TWO COMPUTER PROJECT

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SCATER

RESOURCE MANUAL

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I. THE GEIGER-MARSDEN EXPERIMENTS

In 1911 Ernest Rutherford proposed a nuclear theory of the atom as a result of the alpha particle scattering experiments performed by Geiger and Marsden. In Rutherford's own words:

> "In the early days I had observed the scattering of alpha particles, and Dr. Geiger in my laboratory had examined it in detail. He found, in thin pieces of heavy metal that the scattering was usually small, of the order of one degree. One day Geiger came to me and said, 'Don't you think that young Marsden, whom I am training in radioactive methods, ought to begin a small research?' Now I had thought that too, so I said, "Why not let him see if any alpha particles can be scattered through a large angle?' I may tell you in confidence that I did not believe that they would be, since we knew that the alpha particle was a very fast, massive particle, with a great deal of energy, and you could show that if the scattering was due to the accumulated effect of a number of small scatterings the chance of an alpha particle's being scattered backwards was very small. Then I remember two or three days later Geiger coming to me in great excitement and saying, 'We have been able to get some of the alpha particles coming backwards...' It was quite the most incredible event that has ever happened to me in my life. It was almost as incredible as if you fired a 15-inch shell at a piece of tissue paper and it came back and hit you. On consideration, I realized that this scattering backwards must be the result of a single collision, and when I made calculations I saw that it was impossible to get anything of that order of magnitude unless you took a system in which the greater part of the mass of the atom was concentrated in a minute nucleus. It was then that I had the idea of an atom with a minute massive center carrying a charge. I worked out mathematically what laws the scattering should obey, and I found that the number of particles scattered through a given angle should be proportional to the thickness of the scattering foil, the square of the nuclear charge, and inversely proportional to the fourth power of the velocity. These deductions were later verified by Geiger and Marsden in a series of beautiful experiments."*

The experiments performed by Geiger and Marsden made use of properties of alpha particles previously discovered by Rutherford. Figure 1 is a sketch of Geiger's scattering apparatus. The alpha particles emitted by the radium in the cone-shaped glass tube at the left strike the metal foil placed over the slit. When the deflected alpha particles strike the zinc

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*E. Rutherford, "The Development of the Theory of Atomic Structure", from Background to Modern Science, New York: MacMillan & Co., 1940.

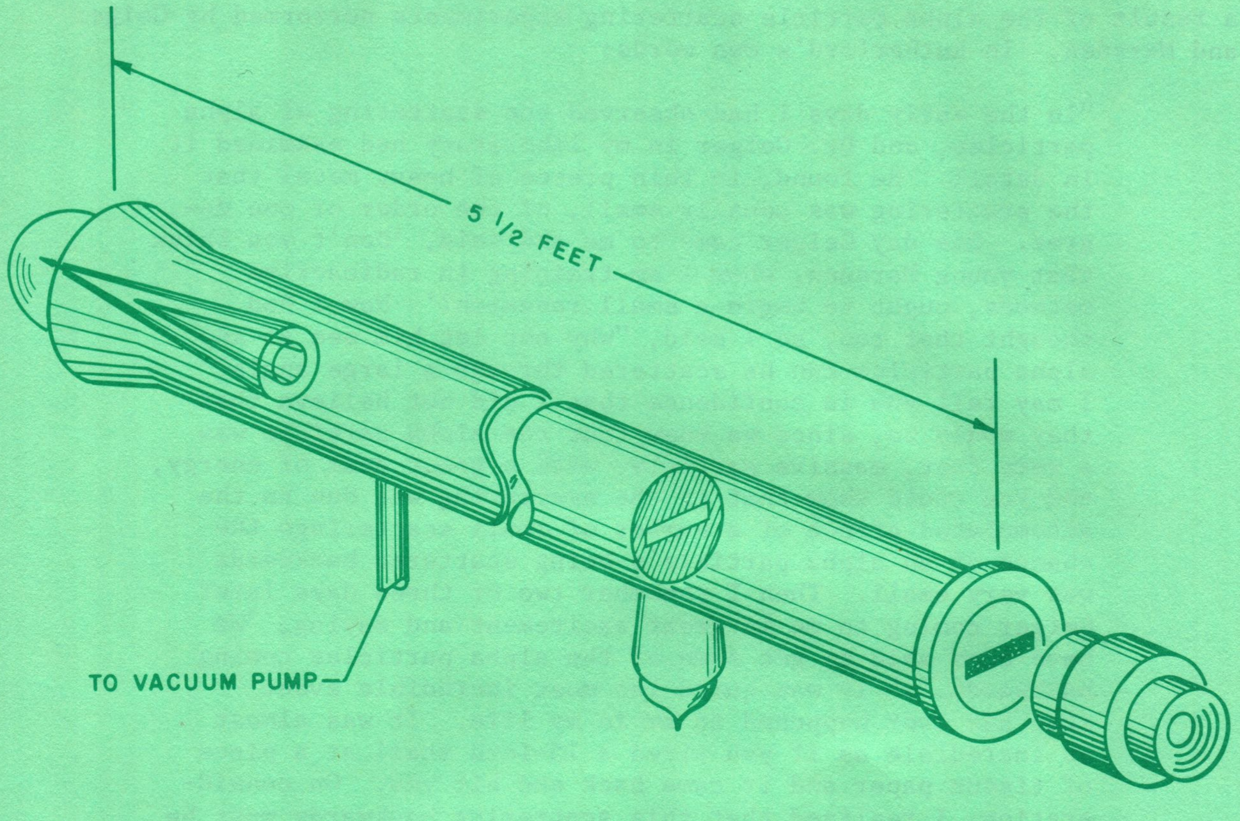

FIGURE 1

sulphide and glass scintillation screen at the right end of the tube, the flashes of light can be viewed through the telescope and the number of flashes recorded.

Figure 2 is a sketch of the Geiger-Marsden experiment to investigate "diffuse reflection", or large-angle deflections of alpha particles.

Alpha particles from a variety of sources were aimed at foils of lead, gold, platinum, tin, silver, copper, iron, and aluminum. The scintillation screen was placed at a 90° angle to the foil, and the lead block shielded

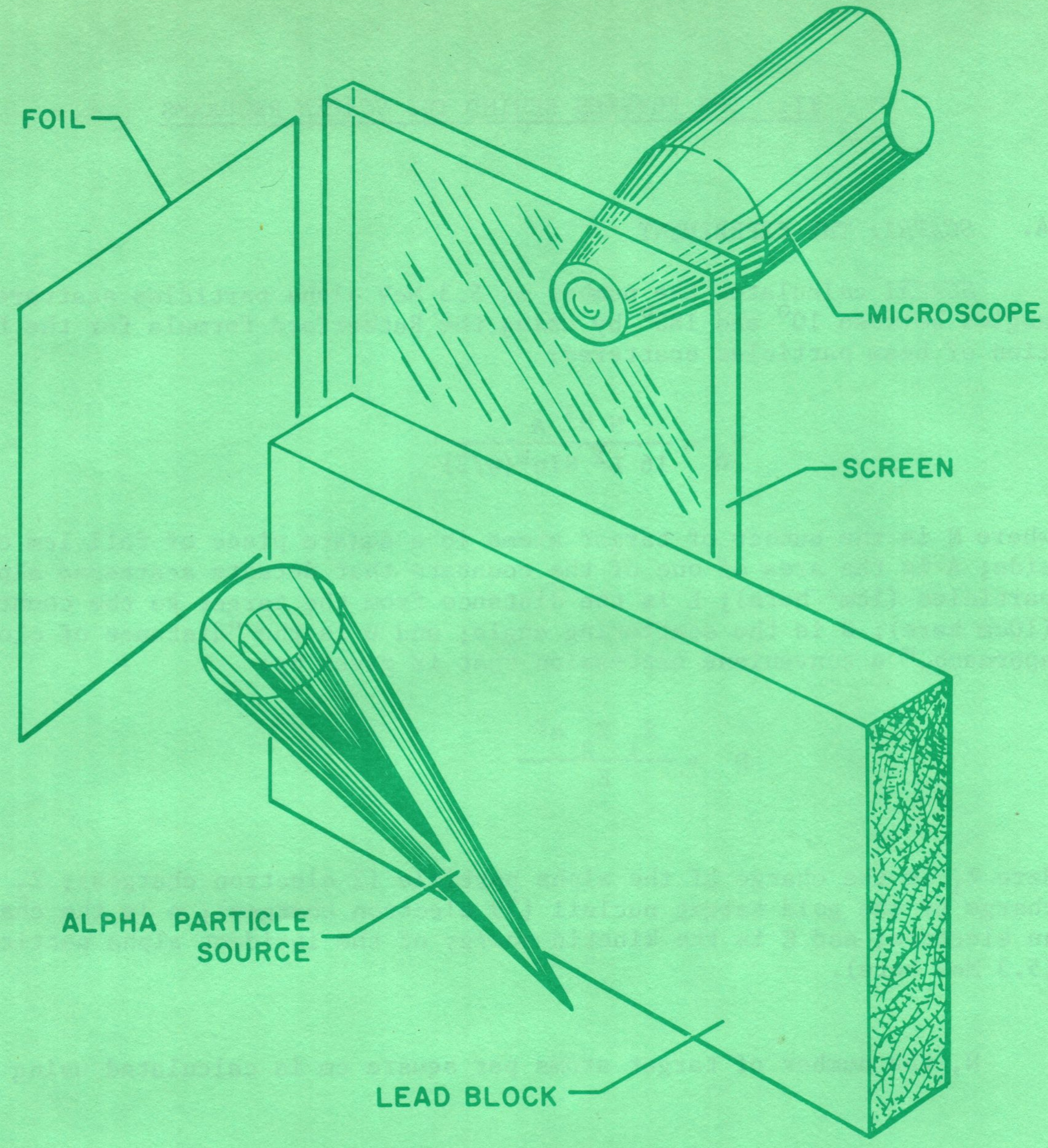

FIGURE 2

the screen from alpha particles coming directly from the cone. The large-angle deflections were observed as before by means of a microscope placed behind the screen.

In these series of experiments Geiger and Marsden found that less than one alpha particle in 8000 was deflected back toward the screen; that the number of alpha particles scattered onto the screen increased with increasing nuclear charge as well as increasing thickness of the foil; and that the more energetic the alpha particles, the higher the proportion of them scattered through a large angle.

II. THE PHYSICS BEHIND THE *SCATER* PROGRAMS

A. *SCATR1:* THE EXPERIMENT

SCATR1 calculates the number of 5.3 MeV alpha particles scattered at angles between 10° and 180° by using the Rutherford formula for the fraction of beam particles scattered:

$$F_D = \frac{N\,D^2\,A}{16\,L^2\,\text{Sin}^4(\theta/2)}$$

where N is the number of target atoms in a square piece of foil 1cm on a side; A is the area of one of the counters that detects scattered alpha particles (1cm^2 here); L is the distance from the target to the counters (10cm here); θ is the scattering angle; and D is the "distance of closest approach," a convenient expression that is given by:

$$D = \frac{Z_1\,Z_2\,e^2}{E}$$

Here Z_1 is the charge of the alpha particle (2 electron charges); Z_2 is the charge of the gold target nucleii (79 electron charges); e is the charge on an electron; and E is the kinetic energy of the incident alpha particle (5.3 MeV here).

N, the number of target atoms per square cm is calculated using

$$N = \frac{V\,H\,T}{W}$$

where V is Avogadros number (6.02×10^{23} atoms per mole) ; H is the density of the target foil (here 19.3 grams/cm^3); T is the thickness of the foil (here 10^{-4}cm or 1 micrometer);and W is the atomic weight of the target material (here 197 grams/mole).

The number of scattered alpha particles going into each counter is calculated by multiplying the calculated value of F_D at the appropriate θ by the number of incident alpha particles:

$$N_D = F_D B$$

where B is the total number of alpha particles hitting the target during the counting period. Since 10^5 particles hit the target each second and the counting period is 10^5 second, B is 10^{10} particles.

The randomness of any scattering experiment is simulated by adding a normally distributed random variable with mean of zero and standard deviation of $(N_D)^{1/2}$ to the value of N_D. This simulates the statistics of actual particle detection. The printed values of the number of particles detected at each angle will show very little variation when the number of detected particles is large, but considerable variation when the number of detected particles is small. For large scattering angles at which the number of detected particles is only about 100, one standard deviation is $(100)^{1/2}$ or 10 and successive measurements taken at the same angle will be quite different. (The variation actually follows a Poisson distribution, but for numbers greater than about 20, the normal or Gaussian distribution is an often-used and accurate approximation.)

The fraction of scattered particles printed for each angle is calculated by dividing the number of scattered particles by the number of incident particles (10^{10}).

B. *SCATR2*: THEORETICAL PREDICTION FROM THREE MODELS

The Hard-Sphere Model

The fraction of the incident particles scattered into a counter of area A at a distance L from the target by a target made up of atoms which are hard spheres of radius R is:

$$F_D = \frac{p_o R^2 N A}{4L^2}$$

where p_o is the probability of interaction between the incident alpha particles and one of the target spheres, (here $p_o = 10^{-5}$), and N is the number of spheres in a piece of target foil 1cm on a side. The fraction scattered into each counter is completely independent of the scattering angle. p_o is fixed at 10^{-5} and R is fixed at 10^{-8} cm, the actual size of a typical atom (gold atoms are slightly larger, hydrogen atoms are slightly smaller). Since this model is wrong, there is no way of "knowing" what the real value of p_o should be. If the probability of interaction is taken as 1, all of the incident particles will scatter from a target foil only one layer of atoms (10^{-8} cm) thick. p_o was chosen to give convenient numbers of scattered particles for the foil thickness used in the experiment simulation in *SCATR1*. Other values of p_o would merely change the total number of scattered particles but not the angular distribution.

As before, N is calculated by

$$N = \frac{V H T}{W}$$

where V is Avogadro's number (6.02×10^{23}); H is the target foil density: T is the target foil thickness; and W is the target foil atomic weight. Values of H and W for copper, silver, and gold are listed in the nomenclature table.

The Thomson Model

The fraction of the incident particles scattered into a counter of area A at a distance L from the target by atoms that are diffuse spheres of positive charge with electrons suspended within (Thomson atoms) is zero for scattering angles greater than a maximum angle θ. The maximum angle at which a Thomson atom can scatter an incident alpha particle of kinetic energy E is

$$\theta_m = \tan^{-1}\left[\frac{Z_1 \; Z_2 \; e^2}{2 R E}\right] = \tan^{-1}\left(\frac{D}{2R}\right)$$

The combination of conditions for which θ_m is a maximum within the constraints of the program is: $Z_2 = 79$ (gold), $E = 2\text{MeV}$. Even for these values, θ_m is only 0.03^o, and no particles are scattered into any of the counters.

The Rutherford Model

The fraction of incident particles scattered into a counter of area A at a distance L and angle θ from a target made up of atoms in which a central charged nucleus creates a Coulomb potential (the Rutherford Model) is

$$F_D = \frac{N D^2 A}{16 L^2 \sin^4(\theta/2)}$$

where N is the number of target atoms per square centimeter, calculated by

$$N = \frac{V H T}{W} .$$

Again, V is Avogadro's number and H, W, and T are the target foil density, atomic number, and thickness.

D is given, as before, by

$$D = \frac{Z_1 Z_2 e^2}{E} .$$

Z_1 and E are the charge and kinetic energy of the alpha particle, Z_2 is the charge of each target atom nucleus, and e is the electron charge.

The terrible problem of units is avoided here and in most of these calculations by replacing e^2 by the famous expression

$$e^2 = r_e m_e c^2 .$$

r_e is the "classical electron radius":

$$r_e = 2.8 \times 10^{-15} \text{ meters} = 2.8 \text{ femtometers}$$

and $m_e c^2$, the rest energy of an electron, is

$$m_e c^2 = .511 \text{ MeV}$$

The shape of the angular distribution is determined by $\sin^4(\theta/2)$. The number of particles scattered is proportional to the thickness of the foil, the area of each counter, the density of the foil, **and the square of the atomic** number of the foil atoms. The number of particles scattered is inversely proportional to the atomic weight of the target atoms, to the square of the alpha particle energy and to the square of the distance from the foil to the counters.

When θ approaches zero, the fraction of particles scattered at the angle θ gets very large. The fraction is prevented from going to infinity (it, in fact, stays less than 1) since for very small θ, the range of θ measured by a counter must be very small and hence A, the area of the counter, must be very small. Although $1/\sin^4(\theta/2)$ goes to infinity for $\theta = 0$, the area of the counter at $\theta = 0$ is also zero, and N_D remains finite. For small angles, where the fraction scattered is relatively high, each alpha particle has a fairly high probability of being scattered by a second atom on its way out of the foil, and the scattering data at angles less than a few degrees (not measured in this simulation) will reflect this multiple scattering.

C. *SCATR3:* TRAJECTORIES

The trajectory of an alpha particle being scattered by a stationary charged nucleus is described (in polar coordinates: r, Φ) by

$$x_o^2 + \frac{D}{2} r - \frac{D}{2} r \cos \Phi - x_o r \sin \Phi = 0 \quad .$$

(See, for instance, E. J. Konipinski, *CLASSICAL DESCRIPTIONS OF MOTION*, p.98.)

Here x_o is the perpendicular distance between an extension of the alpha particle's initial path and the atomic nucleus (the 'impact parameter'). D, the 'distance of closest approach,' is how close the alpha particle could come to the nucleus if its initial path were aiming straight for the nucleus. D is given by

$$D = \frac{Z_1 Z_2 e^2}{E}$$

where Z_1 and E are the charge and kinetic energy of the alpha particle, Z_2 is the charge of the nucleus, and e is the charge on an electron.

Converted to rectangular coordinates, with the alpha particle arriving from the negative y direction, the trajectory equation is

$$x_o^2 + \frac{D}{2}(x^2 + y^2)^{\frac{1}{2}} + \frac{D}{2} y - x_o x = 0$$

where

$$x = r \sin\Phi \quad ; \quad y = -r \cos\Phi$$

When solved for x as a function of y, this equation gives

$$x = \frac{x_o}{x_o^2 - (\frac{D}{2})^2} \left[x_o^2 + \frac{x_o D}{2} \left(y \pm \left[y^2 + x_o^2 - D y\right]^{\frac{1}{2}} \right) \right]$$

The behavior of x as a function of y depends on the value of x_o, the perpendicular distance between the initial alpha particle path and the nucleus:

a) When x_o is greater than D/2:

Only the positive sign in the equation for x is used:

$$x = \frac{x_o}{x_o^2 - (\frac{D}{2})^2} \left[x_o^2 + \frac{x_o D}{2} \left(y + \left[y^2 + x_o^2 - Dy \right]^{\frac{1}{2}} \right) \right]$$

The scattering angle is less than 90° and each value of y on the trajectory corresponds to only one value of x.

b) When x_o is less than D/2:

Use of both the positive and negative sign in the expression for x gives two different values of x for each value of y. This is necessary, since the scattering angle is now greater than 90° and the outgoing alpha particle trajectory again has negative values of y. In this case, the maximum (least negative) value that y attains is

$$y_{max} = -\left(\frac{D}{2} + \left[(\frac{D}{2})^2 - x_o^2 \right]^{\frac{1}{2}} \right)$$

c) When x_o equals D/2:

The trajectory equation becomes

$$\frac{D}{2} + (x^2 + y^2)^{\frac{1}{2}} + y - x = 0$$

and x as a function of y is

$$x = \frac{D}{2} \left(\frac{2y + \frac{D}{2}}{2y + D} \right)$$

Now the maximum value that y takes on is

$$y_{max} = -\frac{D}{2}$$

In each case θ, the angle through which the alpha particle is scattered, is given by

$$\tan(\theta/2) = \frac{D}{2x_o}$$

III. PROGRAM LISTINGS (*Scatr1, Scatr2, Scatr3*)

```
100 REM SCATR1 - ALPHA PARTICLE SCATTERING EXPERIMENT SIMULATION
110 REM COPYRIGHT 1973 - STATE UNIVERSITY OF NEW YORK
120 REM DEVELOPED BY J. BRESMAN, A. CAGGIANO, AND D. SCARL
130 REM PROGRAMMED BY C. LOSIK AND D. SCARL,REVISED BY M. WEISNER
140 REM SCATER IS A SET OF ASSOCIATED PROGRAMS CONTAINING SCATR1,
150 REM SCATR2, AND SCATR3
160 REM LATEST REVISION: 12-12-73
170 RANDOMIZE
180 LET N0=0
190 DIM G(5),H(3),W(3),Z(3)
200 REM AVOGADRO'S NUMBER
210 LET V4=6.02E23
220 REM ELECTRON REST ENERGY (MEV)
230 LET B4=.511
240 REM CLASSICAL ELECTRON RADIUS (CM)
250 LET D4=2.8E-13
260 REM ALPHA PARTICLE CHARGE
270 LET Z4=2
280 REM ATOMIC NUMBER OF GOLD
290 LET Z(3)=79
300 REM ATOMIC WEIGHT OF GOLD
310 LET W(3)=197
320 REM DENSITY OF GOLD
330 LET H(3)=19.3
340 REM LOG OF NO. OF BEAM PARTICLES
350 LET B1=10
360 LET B=100
370 LET E4=5.3
380 LET T=1
390 LET T4=1E-5*T
400 LET A4=1
410 LET L4=10
420 PRINT "INSTRUCTIONS (0=NO,1=YES)";
430 INPUT I
440 IF I=0 THEN 580
450 IF I<>1 THEN 420
460 PRINT"A VERY RADIOACTIVE POLONIUM SOURCE PRODUCES A BEAM OF"
470 PRINT"100,000 ALPHA PARTICLES PER SECOND, EACH HAVING AN ENERGY"
480 PRINT"OF 5.3 MEV. THE BEAM STRIKES A 1 MICROMETER THICK GOLD FOIL."
490 PRINT"FIVE ALPHA PARTICLE DETECTORS CAN BE SET UP TO COUNT THE"
500 PRINT"NUMBER OF SCATTERED PARTICLES DURING A COUNTING PERIOD OF"
510 PRINT"100,000 SECONDS (ABOUT 28 HOURS). EACH DETECTOR HAS AN AREA"
520 PRINT"OF 1 SQ CM AND IS 10 CM AWAY FROM THE GOLD FOIL."
530 PRINT"THE ANGULAR LOCATION OF EACH OF THE COUNTERS CAN BE SET"
540 PRINT"BETWEEN THE LIMITS OF 10 DEGREES AND 180 DEGREES BY TYPING"
550 PRINT"A NUMBER BETWEEN 10 AND 180 WHEN THE COMPUTER ASKS: C()=."
560 PRINT"ZERO DEGREES IS FORWARD SCATTERING AND 180 DEGREES IS "
570 PRINT"BACKWARD SCATTERING. TYPE C()=4 TO END THE PROGRAM."
580 REM TARGET PARTICLES PER CM↑2
590 LET N=T4*V4*H(3)/W(3)
600 REM DISTANCE OF CLOSEST APPROACH
```

SCATR1 (cont.)

```
610 LET D=Z4*Z(3)*B4*D4/E4
620 FOR I=1 TO 5
630 PRINT "C(";I;")=";
640 INPUT G(I)
650 IF G(I)=4 THEN 900
660 IF (G(I)-10)*(180-G(I))>=0 THEN 690
670 PRINT"10<=C(";I;")<=180"
680 GOTO 630
690 NEXT I
700 IF N0>0 THEN 730
710 PRINT TAB(12);"ANGLE   NUMBER SCATTERED    FRACTION SCATTERED"
720 LET N0=1
730 FOR I=1 TO 5
740 LET S=SIN(3.1416*G(I)/360)↑4
750 LET P=N*D*D*A4/(16*L4↑2*S)
760 REM RAW NUMBER SCATTERED
770 LET C=P*B
780 LET Y=RND(1)
790 LET C1=SQR(C)*COS(6.283*Y)*SQR(-2*LOG(Y))
800 REM RANDOMIZED NUMBER SCATTERED
810 LET D1=C+C1
820 LET D2=INT(D1+.5)*(1+SGN(D1))/2
830 LET J=0
840 LET J=J+1
850 IF INT(D1/10↑J)>10 THEN 840
860 LET D5=INT(D1/10↑(J-2)+.5)/10↑(12-J)
870 PRINT TAB(12);G(I);TAB(20);D2;TAB(40);D5
880 NEXT I
890 GOTO 620
900 END
```

```
100 REM SCATR2 - ALPHA PARTICLE SCATTERING - THEORETICAL PREDICTIONS
110 REM COPYRIGHT 1973 - STATE UNIVERSITY OF NEW YORK
120 REM MODELS DEVELOPED BY J. BRESMAN, A. CAGGIANO, AND D. SCARL
130 REM PROGRAMMED BY C. LOSIK AND D. SCARL, REVISED BY M. WEISNER
140 REM SCATER IS A SET OF ASSOCIATED PROGRAMS CONTAINING SCATR1,
150 REM SCATR2, AND SCATR3
160 REM LATEST REVISION: 12-12-73
170 DIM Z(3),H(3),W(3)
180 REM AVOGADRO'S NUMBER
190 LET V4=6.02E23
200 REM ELECTRON REST ENERGY (MEV)
210 LET B4=.511
220 REM CLASSICAL ELECTRON RADIUS (CM)
230 LET D4=2.8E-13
240 REM ALPHA PARTICLE CHARGE
250 LET Z4=2
260 REM TARGET ATOM RADIUS (CM)
270 LET R4=1E-8
280 REM HARD SPHERE INTERACTION PROBABILITY
290 LET P4=1E-5
300 REM ATOMIC NUMBER OF (1=CU,2=AG,3=AU)
310 LET Z(1)=29
320 LET Z(2)=47
330 LET Z(3)=79
340 REM ATOMIC WEIGHT OF (1=CU,2=AG,3=AU)
350 LET W(1)=63.5
360 LET W(2)=107.9
370 LET W(3)=197
380 REM DENSITY OF (1=CU,2=AG,3=AU)
390 LET H(1)=8.96
400 LET H(2)=10.5
410 LET H(3)=19.3
420 LET E4=5.3
430 LET S=3
440 LET T=1
450 LET A4=1
460 LET L4=10
470 PRINT"INSTRUCTIONS (0=NO,1=YES)";
480 INPUT I
490 IF I=0 THEN 600
500 IF I<>1 THEN 470
510 PRINT"SCATR2 PLOTS THEORETICAL PREDICTIONS OF THE FRACTION OF"
520 PRINT"ALPHA PARTICLES SCATTERED AT ANGLES FROM 10 TO 180"
530 PRINT"DEGREES BY THREE DIFFERENT HEAVY ATOM MODELS."
540 PRINT"INPUTS ARE: ALPHA PARTICLE ENERGY (BETWEEN 2 AND 8 MEV),"
550 PRINT"TARGET MATERIAL (1=COPPER,2=SILVER,3=GOLD),TARGET THICKNESS"
560 PRINT"(BETWEEN .5 AND 2 MICROMETERS), DETECTOR SIZE"
570 PRINT"(BETWEEN .5 AND 2 SQ CM), AND DISTANCE FROM TARGET TO"
580 PRINT"DETECTORS (BETWEEN 10 AND 40 CM)."
```

```
590 PRINT
600 PRINT"ENERGY=";E4;
610 INPUT I
620 IF (I-2)*(8-I)>=0 THEN 650
630 PRINT "2<=ENERGY<=8"
640 GOTO 600
650 LET E4=I
660 PRINT"MATERIAL=";S;
670 INPUT I
680 IF (I-1)*(I-2)*(I-3)=0 THEN 710
690 PRINT"1=CU,2=AG,3=AU"
700 GOTO 660
710 LET S=I
720 PRINT "THICKNESS=";T;
730 INPUT I
740 IF (I-.5)*(2-I)>=0 THEN 770
750 PRINT".5<=THICKNESS<=2"
760 GOTO 720
770 LET T=I
780 LET T4=1E-5*T
790 PRINT"SIZE=";A4;
800 INPUT I
810 IF (I-.5)*(2-I)>=0 THEN 840
820 PRINT".5<=SIZE<=2"
830 GOTO 790
840 LET A4=I
850 PRINT"DISTANCE=";L4;
860 INPUT I
870 IF (I-10)*(40-I)>=0 THEN 900
880 PRINT"10<=DISTANCE<=40"
890 GOTO 850
900 LET L4=I
910 REM TARGET PARTICLES PER CM↑2
920 LET N=T4*V4*H(S)/W(S)
930 REM DISTANCE OF CLOSEST APPROACH
940 LET D=Z4*Z(S)*B4*D4/E4
950 REM MODEL CHOICE
960 PRINT"MODEL (1=HARD SPHERES, 2=THOMSON, 3=RUTHERFORD)";
970 INPUT M
980 IF (M-1)*(M-2)*(M-3)<>0 THEN 960
990 REM PREDICTION PLOTS
1000 PRINT
1010 IF M>1 THEN 1050
1020 PRINT"HARD SPHERE MODEL"
1030 LET F=P4*N*R4↑2*A4/(4*L4↑2)
1040 LET F1=8+10*(LOG(F)/LOG(10)+9)
1050 IF M<>2 THEN 1080
1060 PRINT"THOMSON MODEL"
1070 LET F1=7
1080 IF M<3 THEN 1100
1090 PRINT "RUTHERFORD MODEL"
1100 PRINT E4;"MEV ALPHA'S  ";T;"MICRON ";
1110 IF S>1 THEN 1130
1120 PRINT"COPPER";
1130 IF S<>2 THEN 1150
1140 PRINT"SILVER";
1150 IF S<3 THEN 1170
```

```
1160 PRINT"GOLD";
1170 PRINT"  ";A4;"SQ CM COUNTERS ";L4;"CM AWAY"
1180 PRINT
1190 PRINT TAB(15);"FRACTION OF PARTICLES SCATTERED (LOG SCALE)"
1200 GOSUB 1310
1210 FOR I=10 TO 180 STEP 10
1220 IF M<3 THEN 1270
1230 REM RUTHERFORD MODEL
1240 LET S1=SIN(3.1416*I/360)↑4
1250 LET F=N*D*D*A4/(16*L4↑2*S1)
1260 LET F1=8+10*(LOG(F)/LOG(10)+9)
1270 PRINT I;TAB(7);"I";
1280 IF ABS(F1-38)>31 THEN 1370
1290 PRINT TAB(F1);"*"
1300 GOTO 1400
1310 PRINT "        1E-9      1E-8      1E-7      1E-6      1E-5";
1320 PRINT "      1E-4      1E-3"
1330 PRINT "ANGLE:";
1340 PRINT TAB(7);"I  .  . ..I  .  . ..I  .  . ..I  .  . ..I  .  . ..";
1350 PRINT "I  .  . ..I"
1360 RETURN
1370 IF F1<7 THEN 1390
1380 PRINT TAB(57);
1390 PRINT "(";F;")"
1400 NEXT I
1410 GOSUB 1340
1420 PRINT
1430 PRINT"NEXT PREDICTION (1=NEW MODEL, 2=NEW ENERGY, ETC.,";
1440 PRINT"3=END PROGRAM";
1450 INPUT K
1460 IF K=1 THEN 960
1470 IF K=2 THEN 600
1480 IF K<>3 THEN 1430
1490 END
```

```
100 REM SCATR3 - ALPHA PARTICLE TRAJECTORIES
105 REM COPYRIGHT 1973 - STATE UNIVERSITY OF NEW YORK
110 REM MODELS DEVELOPED BY J. BRESMAN, A. CAGGIANO, AND D. SCARL
115 REM PROGRAMMED BY C. LOSIK, M. WEISNER, D. SCARL, AND T. BLOOM
120 REM SCATER IS A SET OF ASSOCIATED PROGRAMS CONTAINING SCATR1,
125 REM SCATR2, AND SCATR3
130 REM LATEST REVISION:12-12-73
135 DIM Z(3),B(6),X(6),A(3,15),L(9)
140 REM ELECTRON REST ENERGY (MEV)
145 LET B4=.511
150 REM VELOCITY OF LIGHT (FEMTOMETERS/FEMTOSECOND)
155 LET C4=3E8
160 REM CLASSICAL ELECTRON RADIUS (FM)
165 LET D4=2.8
170 REM ALPHA PARTICLE CHARGE
175 LET Z4=2
180 REM ALPHA PARTICLE REST ENERGY (MEV)
185 LET M4=3720
190 REM TARGET ATOM RADIUS (FM)
195 LET R4=2E5
200 REM ATOMIC NUMBER OF (1=CU,2=AG,3=AU)
205 LET Z(1)=21
210 LET Z(2)=47
215 LET Z(3)=79
220 LET E4=5.3
225 LET S=3
230 LET G=8
235 FOR P=7 TO 9
240 LET L(P)=0
245 NEXT P
250 LET N1=0
255 PRINT
260 PRINT
265 PRINT"INSTRUCTIONS (0=NO,1=YES)";
270 INPUT I
275 IF I=0 THEN315
280 IF I<>1 THEN 265
285 PRINT"SCATR3 PLOTS THE TRAJECTORIES OF ALPHA"
290 PRINT"PARTICLES SCATTERED FROM INDIVIDUAL HEAVY ATOMS."
295 PRINT"INPUTS ARE: ALPHA PARTICLE ENERGY (BETWEEN 2 AND 8 MEV),"
300 PRINT"TARGET MATERIAL (1=COPPER,2=SILVER,3=GOLD),"
305 PRINT"AND THREE DIFFERENT PERPENDICULAR DISTANCES BETWEEN THE"
310 PRINT"INCIDENT ALPHA PATH AND THE CENTER OF THE TARGET ATOM."
315 PRINT"ALPHA ENERGY=";E4;
320 INPUT I
325 IF (I-2)*(8-I)>=0 THEN 340
330 PRINT "2<=ALPHA ENERGY<=8"
335 GOTO 315
340 LET E4=I
345 PRINT"TARGET MATERIAL=";S;
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350 INPUT I
355 IF (I-1)*(3-I)>=0 THEN 370
360 PRINT "1=CU, 2=AG, 3=AU"
365 GOTO 345
370 LET S=I
375 REM DELETE THE NEXT LINE TO MODIFY MAGNIFICATION EXPONENT
380 GOTO415
385 PRINT"MAGNIFICATION=2.5E";G;"     2.5E";
390 INPUT I
395 IF (I-8)*(11-I)>=0 THEN 410
400 PRINT "8<=MAG. EXPONENT<=11"
405 GOTO 385
410 LETG=I
415 LET G1=10↑(12-G)
420 LET G2=25*G1
425 LET G3=3.2*G1
430 LET G5=7*G3
435 LET R4=R4/G3
440 LET R3=R4↑2
445 IF N1<>0 THEN 465
450 FOR P=1 TO 3
455 LET X(P)=G1*(2*P-28)
460 NEXT P
465 PRINT"CHOOSE X() BETWEEN";-.8*G2;"AND";.8*G2;"(FEMTOMETERS)"
470 FOR P=1 TO 3
475 PRINT"X(";P;")=";X(P);
480 INPUT I
485 IF .8*G2-ABS(I)<0 THEN 475
490 LET X(P)=I
495 LET X(P+3)=I
500 NEXT P
505 PRINT
510 PRINT
515 REM RADIAL ACCELERATION CONSTANT
520 LET A1=Z4*Z(S)*B4*D4*C4↑2/M4
525 REM DISTANCE OF CLOSEST APPROACH
530 LET D=Z4*Z(S)*B4*D4/E4
535 REM INITIAL VELOCITY
540 LET V4=C4*SQR(2*E4/M4)
545 FOR P=1 TO 3
550 FOR J=1 TO 15
555 LET A(P,J)=0
560 NEXT J
565 NEXT P
570 FOR P=1TO3
575 IF X(P)<>0 THEN 590
580 LET Q=3.14159
585 GOTO 595
590 LET Q=ABS(2*ATN(D/(2*X(P))))
595 LET N1=SGN(X(P))*SGN(1.57079-Q)
600 FOR Y1=1TO8
605 LET A(P,Y1)=INT(ABS(X(P)/G1)+.5)*SGN(X(P))+26
610 NEXT Y1
615 IF ABS(Q-1.57079)>.03 THEN630
620 LET A(P,8)=A(P,8)/100+25*SGN(X(P))+26
625 GOTO 715
630 IF Q<1.57079 THEN645
635 LET Y=1
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640 GOTO 650
645 LET Y=15
650 FOR Y1=8TOY STEP SGN(1.57079-Q)
655 LET X=X(P)+G3*(Y1-8)*ABS(SIN(Q)/COS(Q))*V1
660 IF Y1=8 THEN 670
665 LET A(P,Y1)=A(P,Y1)/100+INT(ABS(X/G1)+.5)*SGN(X)+26
670 IF ABS(X)>G2 THEN 685
675 NEXT Y1
680 GOTO 715
685 IFABS(G2-ABS(X))<=ABS(G2-ABS(INT(A(P,Y1-1))-26)*G1)THEN705
690 LET N=Y1-SGN(1.57079-Q)
695 LET A(P,Y1)=(A(P,Y1)-INT(A(P,Y1)))*100
700 GOTO 710
705 LET N=Y1
710 LET A(P,N)=A(P,N)-INT(A(P,N))+25*SGN(X)+26
715 NEXT P
720 PRINT TAB(13);"ALPHA ENERGY:";E4;"MEV";TAB(43);"TARGET ";
725 PRINT"CHARGE:";Z(S)
730 PRINT
735 PRINTTAB(10);"X(1)=";X(1);TAB(30);"X(2)=";X(2);TAB(50);"X(3)=";X(3)
740 PRINT
745 PRINT TAB(31);"(FEMTOMETERS)"
750 PRINT TAB(8);"X=";TAB(15);-20*G1;TAB(25);-10*G1;TAB(35):" 0";
755 PRINT TAB(45);10*G1;TAB(55);20*G1
760 PRINT"Y=";
765 GOSUB 935
770 FOR Y=1 TO 15
775 IF Y<>8 THEN 785
780 LET L(7)=26
785 IF ABS(Y-8)>R4 THEN 800
790 LET L(8)=INT(3.2*SQR(R3-(Y-8)↑2)+.5)+26
795 LET L(9)=52-L(8)
800 FOR P=1 TO 3
805 LET L(P)=INT(A(P,Y))
810 LET L(P+3)=INT((A(P,Y)-L(P))*100+.5)
815 NEXT P
820 PRINT G3*(Y-8);TAB(10);"I";
825 LETJ=62
830 FOR P=1 TO 9
835 IF ABS(L(P)-J/2)>=J/2 THEN 850
840 LET J=INT(L(P)+.5)
845 LET I=P
850 NEXT P
855 IFJ=62THEN950
860 LET L(I)=0
865 PRINT TAB(10+J);
870 IF Y<>8THEN 880
875 IF J=26 THEN 910
880 IF (I-1)*(I-4)<>0 THEN 890
885 PRINT "1";
890 IF (I-2)*(I-5)<>0 THEN 900
895 PRINT "2";
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900 IF (I-3)*(I-6)<>0 THEN 910
905 PRINT "3";
910 IF I<>7 THEN 920
915 PRINT "N";
920 IF I<8 THEN 825
925 PRINT "B";
930 GOTO 825
935 PRINT TAB(11);"-----I---------I---------I---------I";
940 PRINT "----------I-----"
945 RETURN
950 PRINT
955 IFY=15 THEN 965
960 PRINT
965 NEXT Y
970 GOSUB 935
975 FORP=1TO3
980 PRINTTAB(23*(P-1));"ANGLE(";P;")=";
985 IF X(P)<>0 THEN 1000
990 PRINT 180;
995 GOTO1005
1000 PRINT INT(ABS(360/3.14159*ATN(D/(2*X(P))))*100)/100;
1005 NEXTP
1010 PRINT
1015 PRINT
1020 PRINT"1=NEW DISTANCES, 2=NEW ENERGY OR TARGET, 3=END PROGRAM";
1025 INPUT I
1030 PRINT
1035 IF I=1 THEN 470
1040 IF I=2 THEN 315
1045 IF I<>3 THEN 1020
1050 END
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IV. *SCATER* NOMENCLATURE

V4 = Avogadro's number = 6.02 E23 atoms/mole

B4 = Electron rest energy = .511 MeV

C4 = Velocity of light = 3 E8 meters/second = 3 E8 femtometers/femtosecond

D4 = Classical electron radius = 2.8 E-13 cm = 2.8 femtometers

Z(1) = Atomic number of copper = 29

Z(2) = Atomic number of silver = 47

Z(3) = Atomic number of gold = 79

W(1) = Atomic weight of copper = 63.5 amu

W(2) = Atomic weight of silver = 107.9 amu

W(3) = Atomic weight of gold = 197 amu

H(1) = Density of copper = 8.96 g/cm^3

H(2) = Density of silver = 10.5 g/cm^3

H(3) = Density of gold = 19.3 g/cm^3

E4 = Alpha particle energy (MeV)

Z4 = Alpha particle charge = 2

M4 = Alpha particle rest energy = 3720 MeV

B = Number of beam particles

B1 = Log of number of beam particles

R4 = Target atom radius = 2 E-8 cm = 200,000 femtometers

T4 = Film thickness (cm)

T = Film thickness(micrometers)

P4 = Hard-sphere interaction probability = 1 E-5

A4 = Counter area (cm^2)

L4 = Counter distance from target (cm)

M = Model index: 1=spheres; 2=Thomson; 3=Rutherford

S = Material index: 1=copper; 2=silver; 3=gold

D = Distance of closest approach

N = Number of target particles per square cm.

V. BIBLIOGRAPHY

PSSC: PHYSICS
D. C. Heath and Co., Boston (1968)

Pages 594-610 contain a discussion of scattering that is similar in spirit to *SCATER*.

Andrade, E. N. deCosta: *RUTHERFORD AND THE NATURE OF THE ATOM*
Doubleday Science Study Series, New York (1964)

Historical, biographical, and scientific story of Rutherford's researches.

Leighton, R. B.: *PRINCIPLES OF MODERN PHYSICS*
McGraw-Hill Book Company, New York (1959)

Pages 485-511 -- Moderately advanced treatment of particle scattering in a standard modern physics book.

Romer, A.: *THE RESTLESS ATOM*
Doubleday and Co. (Anchor Books), New York (1960)

Pages 129-141.

Tipler, P. A.: *FOUNDATIONS OF MODERN PHYSICS*
Worth Publishing Co., New York (1969)

Pages 147-162 -- Clearly outlined calculations of Rutherford scattering.